

THE CONTROL OF RESPONDING BY SOUNDS: UNUSUAL EFFECT OF REINFORCEMENT

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Naive rats were trained to respond on one lever in the presence of noise bursts from one speaker and on a second lever in the presence of noise bursts from a second speaker. The speakers were mounted behind the levers. When responding on the lever adjacent to the sounding speaker was reinforced, control developed within fewer than five trials. When responding on the nonadjacent lever was selectively reinforced, responding on the lever adjacent to the sounding speaker increased in probability for several sessions. Naive rats were trained to respond on the nonadjacent lever following preexposure to the sound. Responding on the lever adjacent to the sounding speaker increased in probability, showing that novelty was not responsible for the effect. Naive rats were run on automaintenance procedures in which there was no explicit pairing of sound and magazine operation, 100% pairing of sound and magazine operation, or magazine operation following 40% of sound presentations. None of the rats acquired the response of approaching and sniffing the sounding speaker, indicating that sound-magazine pairing was not responsible for the effect.

Key words: auditory discrimination, lever press, reinforcement, rats

Mammals have evolved a number of specific abilities which enable them to acquire certain auditory discriminations readily. For example, the ability of rats and monkeys readily to discriminate the position of sounds is a function of the complexity of the spectral content of the sound (Beecher & Harrison, 1971; Brown, Beecher, Moody, & Stebbins, 1975; Harrison & Beecher, 1969; Harrison & Briggs, 1977), and of the relative positions of the sound source and response sites (Downey & Harrison, 1972, 1975; Harrison, Downey, Segal, & Howe, 1971; Harrison, Iversen, & Pratt, 1977). White noise is more salient than a pure tone (Segal & Harrison, 1978), and hedgehogs, in contrast to cats and tree shrews, cannot discriminate the position of a pure tone below about 15 kHz, although such sounds are well within their range of hearing (Masterton, Thompson, Bechtold, & Robards, 1975; Ravizza, Heffner, & Masterton, 1969).

It is the purpose of the present experiment to further investigate specialization in audi-

tory discrimination. The general approach to the problem is to find an auditory discrimination which is rapidly acquired (suggestive of specialization) and then to analyse the discrimination with respect to possible specializations which are responsible for the rapid acquisition. The discrimination of the position of sounds of complex spectral content is acquired within one or two trials (Beecher & Harrison, 1971) and is thus suitable for investigation of the special processes underlying the rapid acquisition. Rapid acquisition may depend on a special effect of reinforcement upon the response of approaching the sound source. When an animal behaviorally interacts with a sound source under natural conditions, the source must necessarily be approached. The ubiquity of the need for this approach response over the evolutionary history of the animal may be reflected in the behavioral effect of reinforcing a response in the presence of the sound. Briefly, whatever response is differentially reinforced in the presence of a sound, the response of approaching the sound may be strengthened. In the present experiment, the effect of reinforcing an arbitrary (nonapproach) response in an auditory position discrimination on the strength of the response of approaching the sound was investigated.

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EXPERIMENT 1

Auditory position discrimination has been studied in rats and monkeys using an apparatus containing two levers with a speaker mounted adjacent to each lever. If, in a trial-by-trial procedure, a response on the lever adjacent to the sounding speaker was reinforced, control of responding by sound position developed within one or two trials (Beecher & Harrison, 1971). In this arrangement the response of approaching the sound source (and the lever), as well as that of pressing the lever, was reinforced. The same arrangement was used in the present experiment except that responding on the lever adjacent to the nonsounding speaker was reinforced. In this procedure, the response of approaching the sounding speaker was not reinforced. The primary question is whether this procedure strengthens or weakens the response of approaching the sounding speaker during acquisition of the discrimination.

METHOD

Subjects

Five male albino rats, Sprague-Dawley strain, served. The animals, 90 days old at the start of the experiment and experimentally naive, were maintained at approximately 80% of their ad libitum feeding body weight.

Apparatus

The apparatus consisted of a wire mesh enclosure, 21.5 cm by 27.5 cm by 18.5 cm high. Two levers, R1 and R2, were symmetrically mounted on one wall 8 cm above the floor and 7 cm from the sides of the enclosure. Two speakers, S1 and S2 (University type T1800), were positioned one behind each lever, and the sound was conveyed to an area immediately over the lever by a 1.5 cm diameter plastic tube. A liquid food dispenser was centrally mounted on the opposite wall, 3 cm above the floor. The feeder dispensed .1 cc of diluted sweetened condensed milk (two volumes of water to one volume of milk) at each operation. A 5-w 110-V houselight mounted in the center of the ceiling of the enclosure was continuously on for the duration of each session. The experimental enclosure stood in the center of a room 2.5 m by 2.5 m by 3 m high. The experiment was controlled by Grason-Stadler solid state and relay programming

equipment, and responding on the two levers was collected on two separate Gerbrands cumulative recorders (type C3).

The sound used was selected to be (a) below the aversive threshold in all parts of the enclosure (below 90 dB) (Barry & Harrison, 1957; Harrison & Abelson, 1959) and (b) .f complex spectral content with substantial components over 20 kHz. The sound consisted of .3-sec bursts of noise presented at the rate of two bursts per second. Acoustic measurements were made using a Bruel and Kjaer $\frac{1}{4}$ -in. condenser microphone, calibrated with a Bruel and Kjaer pistonphone (4220). The acoustic signal in the enclosure was equally intense, within ± 5 dB, from 4 kHz to 40 kHz, and was adjusted to an intensity of 60 dB, reference $20 \mu\text{N}/\text{m}^2$, at a point .5 cm from the speaker opening. The intensity at the geometrical center of the cage was 43 dB, and the sound was above the animal's threshold at all points of the enclosure (Harrison & Turnock, 1975). The noise bursts were turned on and off using a Grason-Stadler electronic switch (1287B) set to "fast."

Procedure

Animals were trained on a trial-by-trial procedure to respond to one lever when the sound was presented through one speaker and on the other lever when the sound was presented through the other speaker.

A trial commenced with the presentation of noise bursts through either the left or the right speaker, in an irregular order which differed for each session. A variable intertrial interval of 45 sec was used, with the restriction that a trial could not set up in less than 5 sec following a response on either lever. A trial was terminated by a single response on either lever. Sessions were 30 min long. Two groups of animals were used. For Group 1 (two rats, adjacent discrimination) a single response on the lever next to the sounding speaker was reinforced, but a single response on the opposite lever was not reinforced. The animals received 10 sessions. For Group 2 (three rats, nonadjacent discrimination), a single response on the lever remote from the sounding speaker was reinforced, but a single response on the lever next to the sounding speaker was not reinforced. These three animals received a sufficient number of sessions for the discrimination to reach a stable level (at least 16 sessions).

Preliminary training was the same for both groups. During all phases of preliminary training, the speakers were unplugged but the program circuitry was otherwise unaltered. Animals were shaped to press both levers, and hand training was continued until the rate of responding on both levers was about the same. Next, the animals were run for from two to five sessions on the full program (with the speakers still unplugged) until they were responding on both levers at a steady rate. Although the sound was not presented in these sessions, the circuitry collected data in terms of trials. These numbers were used to calculate the percentage of "adjacent responses" exactly as they were used during discrimination training, and they provided a baseline against which the acquisition of the discrimination could be judged.

RESULTS

The results were plotted as the percentage of responses made on the lever next to the sounding speaker. This percentage was calculated by dividing the total number of adjacent responses in a session by the total number of trials, and then multiplying by 100.

Group 1 (adjacent discrimination). The percentage of adjacent responses for these two animals is shown in Figure 1. As can be seen, acquisition of the discrimination was extremely rapid. These data confirm results reported by Harrison et al., (1971) and by Beecher and Harrison (1971). The baseline percentages of no sound "adjacent responses" are presented for both groups in Figures 1 and 2. As expected, these data points were near 50%.

Group 2 (nonadjacent discrimination). The data, in terms of percentage of adjacent responses, are shown for these three animals in Figure 2. Responding came under the control of the sound during the first two to three sessions, but the probability of the reinforced (reversed) response decreased while the nonreinforced (adjacent) response increased in probability. Since the adjacent responses were not reinforced, they could not increase to near 100% because responding would be extinguished. Also, in the long term (five to six sessions; see Figure 2), these approach responses were either extinguished or prevented by the strengthening of the reinforced response of approaching the nonsounding speaker. This

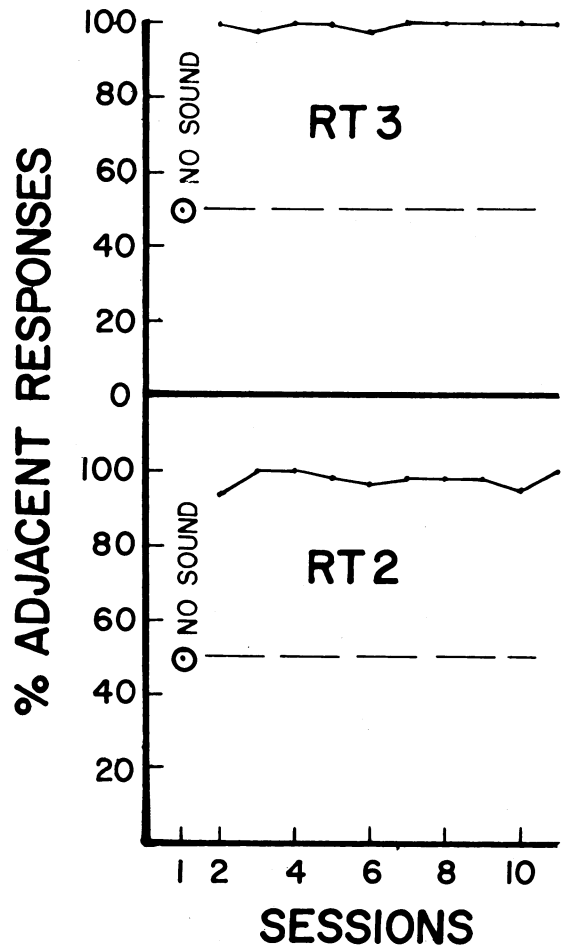


Fig. 1. Percentage of adjacent responses per session. The point marked "no sound" gives the percentage of reinforced responses during the last session (VI 45-sec) before the start of adjacent discrimination training.

paradoxical stimulus control persisted for five to seven sessions and then was lost (approximately 50% adjacent responses). Control by position of the sound then redeveloped in all animals, with the percentage of adjacent responses falling to low levels. Beecher and Harrison (1971) obtained the same increase in adjacent (nonreinforced) responses in the two rats they studied, using a nonadjacent procedure similar to that used here.

The numbers on which the percentages in Figures 1 and 2 were calculated are given in Table 1.

Discussion

The results of Experiment 1 suggest that the effect of reinforcing an arbitrary response is

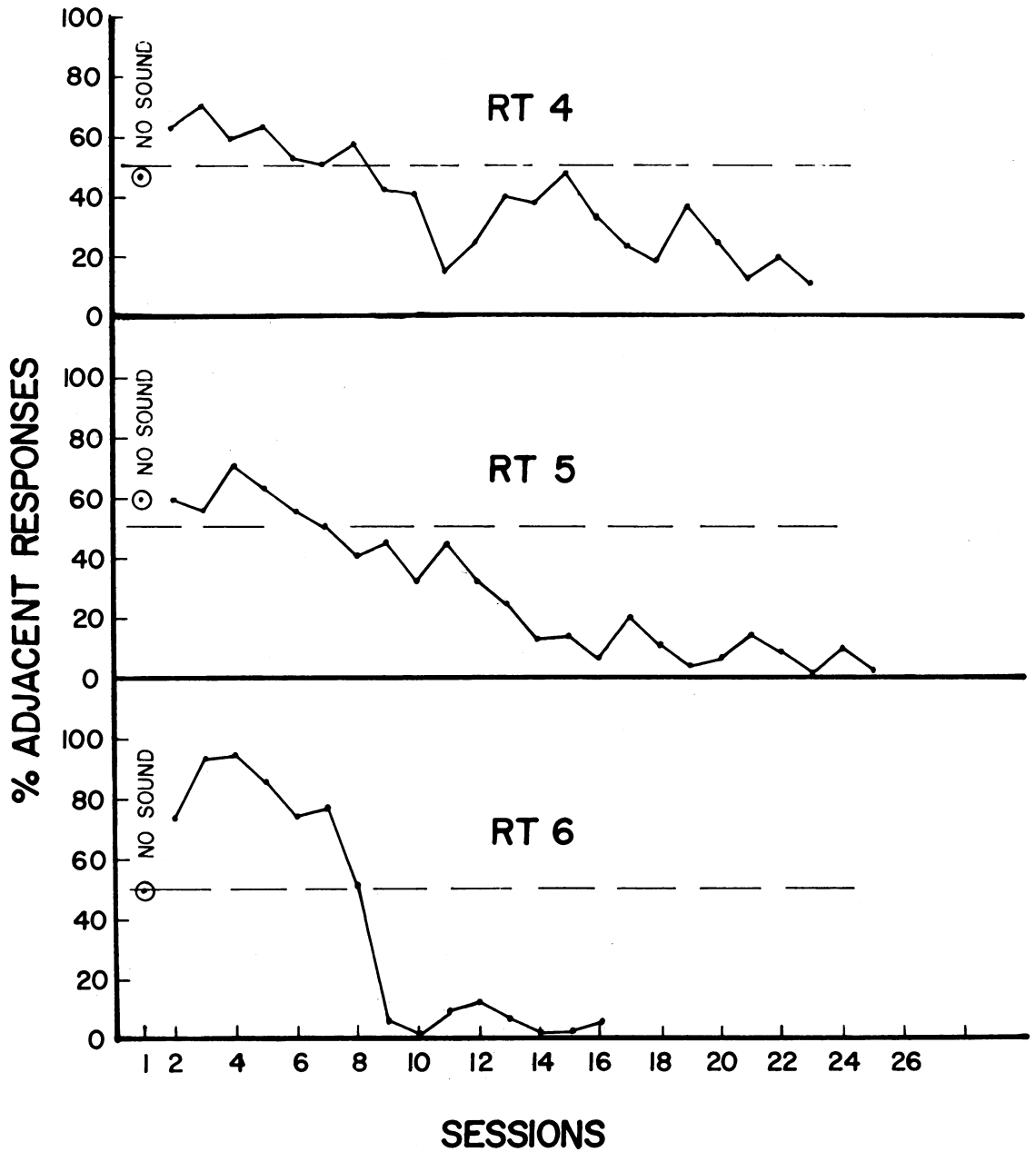


Fig. 2. Percentage of adjacent responses per session. The point marked "no sound" gives the percentage of reinforced responses during the last session (VI 45-sec) before the start of nonadjacent discrimination training.

to strengthen the response of approaching the sound source. However, approaching the sound source may not be the direct function of reinforcement but may depend on properties of the sound, such as its novelty when first presented in discrimination training. The conse-

quences of this possibility for the adjacent and nonadjacent discriminations are as follows.

There was no evidence of an acquisition curve for the animals trained on the adjacent discrimination. This suggests either that the animals had a preexisting tendency to ap-

Table 1

Numbers used to calculate the percentage of adjacent responses in Figures 2 and 3. The first number is the total number of adjacent responses, and the second number is the total number of trials.

Session	RT 2	RT 3	RT 4	RT 5	RT 6
1*	21/42	22/44	21/44	27/45	23/46
2	44/46	44/44	29/45	26/44	32/43
3	46/46	45/46	25/43	24/41	43/46
4	42/42	45/45	24/42	35/49	43/46
5	46/47	46/46	28/44	29/45	39/45
6	44/45	43/44	22/41	23/46	35/47
7	40/42	43/43	21/42	22/43	32/42
8	44/45	46/46	25/44	19/45	22/42
9	43/44	44/44	20/45	19/43	3/48
10	43/45	45/45	18/42	16/47	0/45
11	44/44	46/46	7/44	19/40	5/45
12	—	—	10/40	15/42	3/45
13	—	—	17/42	12/45	1/45
14	—	—	16/41	7/42	1/46
15	—	—	22/45	7/44	2/47
16	—	—	15/45	4/45	—
17	—	—	12/45	10/46	—
18	—	—	9/46	6/44	—
19	—	—	18/46	2/46	—
20	—	—	11/44	3/45	—
21	—	—	6/46	7/46	—
22	—	—	9/45	4/43	—
23	—	—	5/44	1/45	—
24	—	—	6/46	5/46	—
25	—	—	—	3/45	—

*Last prediscrimination session.

proach low-intensity novel sounds, or that only one or two trials in which responding is reinforced are required to produce near 100% adjacent responding. The sound was novel when it was first introduced, and many novel events evoke approach and sniffing behavior in small mammals (Cowan & Barnett, 1975). The adjacent responses at the beginning of the first session might have been evoked by the (then) novel sound, and these responses would be reinforced. As the novelty of the sound decreased, the animals continued to give adjacent responses because of the reinforcement of these when the sound was novel.

This explanation is less satisfactory for the animals run on the reversed discrimination. At the beginning of the first session, the novelty of the sound would produce adjacent responses (the percentage of nonreinforced responses would be above chance). As the novelty of the sound decreased, the effect of differential reinforcement of responding on the opposite lever would strengthen that response. It seems very unlikely, however, that the novel status of the sound evoked adjacent responses

for the four or more sessions that the percentage of adjacent responses was above 50%. Experiment 2 was designed to see whether novelty significantly contributed to adjacent responding early in training, and also to see whether, in the absence of novelty, acquisition of the adjacent and reversed discrimination was the same as was obtained in Experiment 1.

EXPERIMENT 2

There were two parts to Experiment 2. In the first part, animals were studied using the identical discrimination procedure to Experiment 1, except that the feeder was disconnected from the program circuitry. Sound trials were presented and responding was counted in terms of "reinforced" and "nonreinforced" trials, but food was not delivered. Therefore, any behavioral effect of the sound could not be attributed to reinforcement but would be due to the novelty of the sound. Responding was maintained by an independent variable interval schedule which set up reinforcements in the intertrial interval on one or the other of the two levers, in an irregular order. This schedule was restricted to the degree that no response within 10 sec of a trial was reinforced (explicit nonpairing of sound with food). This restriction prevented any behavioral effect of the sound from being due to the pairing of the sound with operation of the food magazine. The random reinforcement of responding in both the presence and the absence of the sound (Rescorla, 1967) was not used because one major purpose of the experiment was to determine if the sound itself (in the absence of any reinforcement) produced control of responding by position, especially early in the first session.

For the second part of Experiment 2, the animals were divided into two groups and given discrimination training (the feeder was reconnected to the discrimination program and the independent variable interval schedule was disconnected). One group received adjacent and the other group reversed discrimination training. Thus, these two groups received discrimination training using sounds to which they had previously been exposed.

METHOD

Subjects

Six naive male albino rats, Sprague-Dawley strain, 90 days old at the start of the experi-

ment, served. Body weight was reduced to and maintained at about 80% of that under *ad libitum* feeding.

Apparatus

The animal enclosure, discrimination program, and noise bursts were identical with those of Experiment 1. A second tape timer was added to the equipment and used to program the 45-sec variable-interval schedule on which responding in the intertrial interval was reinforced.

PROCEDURE

Preliminary training was identical with Experiment 1. When the animals were ready to be changed to "discrimination" training, the speakers were plugged in and the feeder was disconnected from the discrimination program and connected to the second 45-sec variable-interval program. The animals were run for three sessions in the nonreinforced "discrimination" program. As in Experiment 1, a response on either lever in the presence of the sound terminated the trial. During intertrial intervals, reinforcements were set up on one or the other lever (in irregular order) by the second 45-sec variable-interval program with the limitation that no response within 10 sec of a sound was reinforced.

After three sessions, the feeder was reconnected to the discrimination program and the second variable-interval program was discontinued. Three animals were run on the adjacent and three on the reversed discrimination. Training was continued until the percentage of adjacent responses appeared to have reached a stable level.

RESULTS

In Figures 3 and 4, the results of Part 1 are summarized in terms of the percentage of adjacent responses (first three sessions). The numbers on which the percentages are based are given in Table 2. The animals gave near 50% adjacent responses for all the sessions, indicating no stimulus control by the position of the sound. On the assumption that the sound position might control responding for the first few trials of the first session when the sound was novel, the percentage of adjacent responses during the first 10 trials of the first session was compared with the percentage of adjacent responses for the remainder of the

Table 2

Experiment 2, Part 1: Numbers used to calculate the percentage of adjacent responses in the first three sessions. The first number is the total number of adjacent responses and the second number is the total number of trials.

Session	RT 99	RT 102	RT 103	RT 106	RT 107	RT 108
1	29/50	25/45	21/42	23/42	24/45	26/40
2	24/43	20/45	21/40	24/40	23/43	22/40
3	25/50	23/42	16/40	17/40	22/44	23/42

session. These data are presented in Table 3. Only two animals, RT 99 and RT 108, showed strong indication that the sound evoked adjacent responses during the first 10 trials. The percentage of adjacent responses was at chance levels (50%) for the remainder of the session for all animals. These data indicate only a weak tendency for the sound, when novel, to produce adjacent lever responses.

The results of the second part of the experiment are shown in Figure 3 (reversed discrimination) and Figure 4 (adjacent discrimination). Five of the six animals continued to give near 50% adjacent responses for two to three sessions; in both groups, the percentage of adjacent responses then increased. The reversed group continued to give about 50% adjacent responses for five or six sessions; the percentage of adjacent responses then gradually fell to 10% or less. The numbers on which these percentages in Figures 3 and 4 are based are given in Table 4.

DISCUSSION

The results of the first part of Experiment 2 showed that the sound had virtually no control over the location of lever responses. In contrast, the adjacent discrimination animals in Experiment 1 gave near 100% adjacent re-

Table 3

Experiment 2, Part 1: Percentage of adjacent responses in the first 10 trials and for the remainder of the first session. The numbers in parentheses are the total number of adjacent responses (first number) and the total number of trials (second number).

Animal	First 10 trials	Remainder
RT 99	100% (10/10)	48% (19/40)
RT 102	50% (5/10)	57% (20/35)
RT 103	60% (6/10)	47% (15/32)
RT 106	70% (7/10)	50% (16/32)
RT 107	50% (5/10)	54% (19/35)
RT 108	90% (9/10)	57% (17/30)

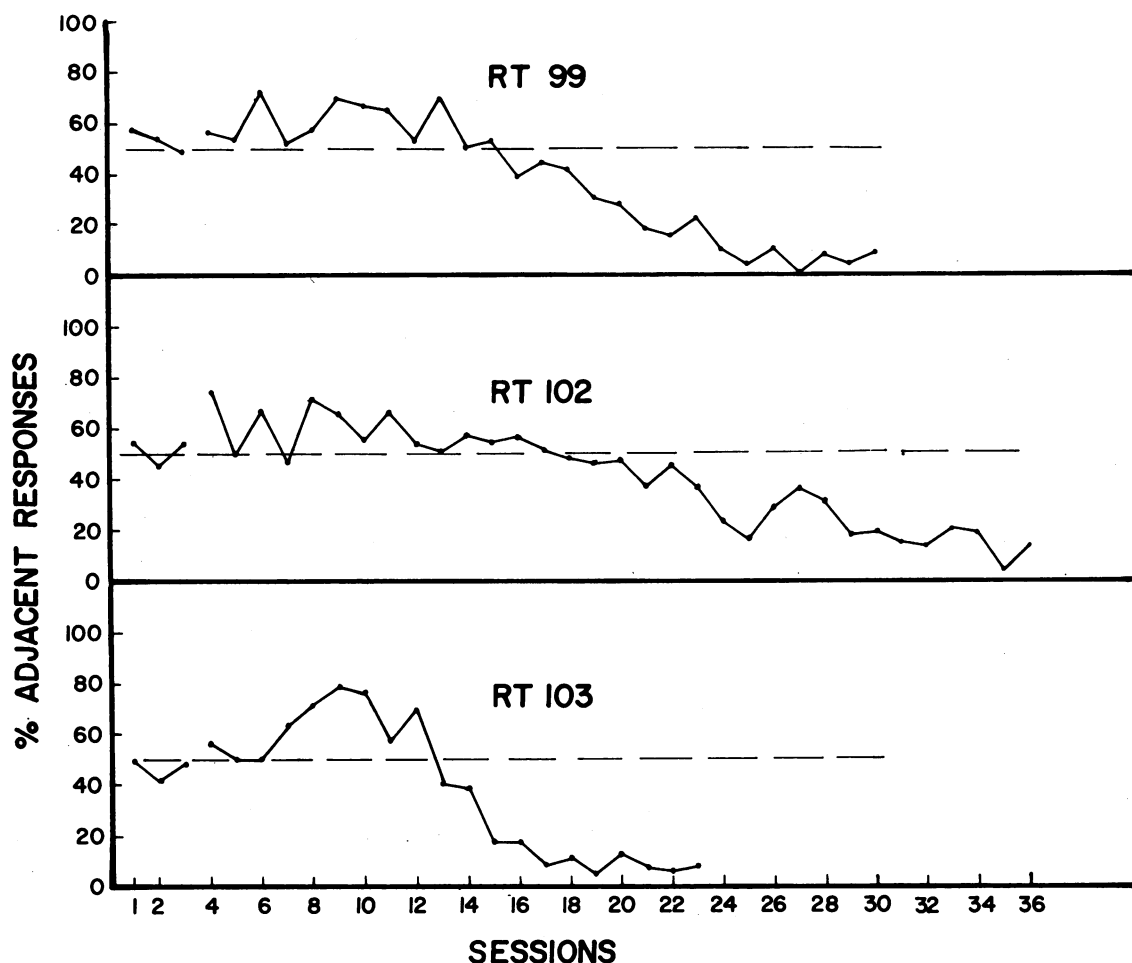


Fig. 3. Percentage of adjacent responses per session. For the first three sessions, responding in the presence of the sound was not reinforced. At session 4, the reversed discrimination procedure was started.

sponses in the first three sessions. Thus, this high percentage level was not due to the novelty of the sound but to the reinforcement of responding in the presence of sound, and/or the pairing of the sound with the operation of the food magazine. This latter pairing would seem unlikely to produce lever responding for the first 20 or so trials of the first session. It appears, therefore, that reinforcement of responding was responsible for the high percentage of adjacent responses in the first session and especially in the first few trials of the adjacent discrimination in the first experiment.

The adjacent group in the first experiment acquired the discrimination within a few trials, whereas the adjacent group in the second experiment required 2 to 10 sessions (80

to about 400 trials). One difference between these groups was that the sound was novel for one and not for the other.

To say that a sound is not novel is to say that the animal was exposed to the sound under some particular condition, and it might be the condition of exposure rather than the lack of novelty which was responsible for the difference. The animals were exposed to the sound under conditions of nonreinforcement of responding. Findings of Downey and Harrison (1972), however, indicate that it was not the lack of reinforcement which was responsible for the difference between the groups. Downey and Harrison studied squirrel monkeys in a nonadjacent discrimination in which responding on either lever in the presence of the sound was reinforced. The animals were

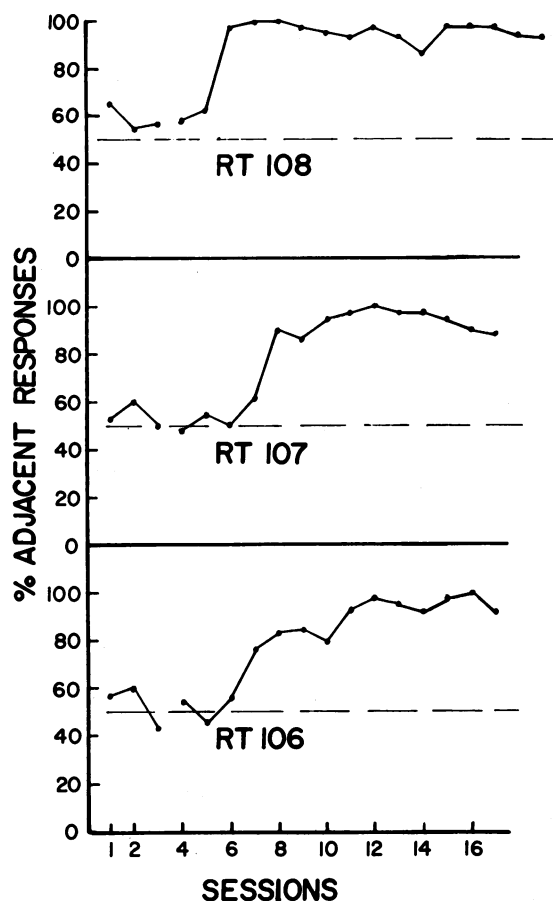


Fig. 4. Percentage of adjacent responses per session. For the first three sessions, responding in the presence of the sound was not reinforced. At session 4, the adjacent discrimination procedure was started.

then trained on an adjacent discrimination using the same sound. They required two to five sessions to reach better than 90% adjacent responses. On the other hand, naive monkeys trained on the adjacent discrimination without preexposure acquired the discrimination as rapidly as the adjacent group of rats in the first experiment reported here. Thus, preexposure to the sound retarded the subsequent discrimination whether or not it had been associated with reinforcement. Thus, novelty seemed to be the significant feature. It appears that sound novelty and reinforcement interact such that reinforcement of a response in the presence of a novel sound has a greater effect on that response than reinforcement in the presence of a non-novel sound.

The effect of preexposure to the sound on

Table 4

Experiment 2, Part 2: Numbers used to calculate the percentage of adjacent responses in Figures 4 and 5. The first number is the total number of adjacent responses, and the second number is the total number of trials.

Session	RT 99	RT 102	RT 103	RT 106	RT 107	RT 108
4	24/44	30/40	24/44	22/40	19/40	23/40
5	26/50	21/40	20/40	18/40	22/40	25/40
6	29/41	27/41	22/42	24/43	20/40	39/40
7	23/44	21/44	19/45	33/44	26/42	40/40
8	30/50	28/39	32/45	35/43	39/43	43/43
9	30/43	27/40	31/40	38/45	37/43	42/43
10	31/45	28/50	31/42	37/46	40/42	40/42
11	25/38	27/40	25/44	42/45	41/42	40/43
12	24/45	22/40	30/43	41/42	43/43	42/43
13	28/40	24/45	20/48	41/43	42/43	41/43
14	22/43	26/46	17/44	41/45	41/43	41/47
15	22/40	25/45	8/45	43/44	40/44	41/42
16	17/45	26/45	8/47	43/43	39/43	43/44
17	18/42	23/43	4/45	40/43	38/43	46/47
18	18/43	21/43	4/43	—	—	40/42
19	13/44	21/45	3/45	—	—	42/45
20	18/48	22/47	5/42	—	—	—
21	8/47	17/44	4/53	—	—	—
22	8/48	21/46	4/53	—	—	—
23	9/44	18/47	4/42	—	—	—
24	4/46	10/47	—	—	—	—
25	1/38	8/48	—	—	—	—
26	4/42	13/43	—	—	—	—
27	0/44	15/44	—	—	—	—
28	3/50	11/42	—	—	—	—
29	2/45	8/43	—	—	—	—
30	3/43	9/44	—	—	—	—
31	—	7/47	—	—	—	—
32	—	6/46	—	—	—	—
33	—	9/47	—	—	—	—
34	—	8/47	—	—	—	—
35	—	1/44	—	—	—	—
36	—	6/50	—	—	—	—

the subsequent development of the adjacent discrimination is probably another example of the effect of stimulus exposure originally called "latent inhibition" by Lubow (Lubow & Moore, 1959). Preexposure to a stimulus makes that stimulus less effective as a CS in classical conditioning procedures and in variations of the Estes-Skinner procedure (see Lubow, 1973, for a review). Similar effects of retardation have been found in instrumental discriminations following preexposure to the positive and negative discriminative stimuli (Halgren, 1974; Mellgren & Ost, 1971).

The reversed discrimination animals of the second experiment gave the same results as the reversed discrimination animals of the first experiment; that is, the nonreinforced response increased in probability for 5 to 10 sessions.

Thus, the above 50% level of adjacent responses of the reversed discrimination animals in Experiment 1 was not due to novelty of the sound. Since the percentage of adjacent responses was near 50% for the three exposure sessions, the increase in adjacent responding was due either to an effect of differential reinforcement or to the pairing of the sound with the operation of the food magazine.

EXPERIMENT 3

The results of Experiment 2 suggest that there is an interaction between sound novelty and reinforcement such that reinforcement is more effective in the presence of novel than of familiar sounds (compare Figures 1 and 4). However, this interpretation may be objected to on the grounds that the sound was an S— during the three preexposure sessions and also that a response was necessary to terminate a trial and initiate the intertrial interval in which responding was reinforced. The purpose of Experiment 3 was to expose animals to the sound before adjacent discrimination training under conditions in which the sound was neither an S— nor terminated by a lever response in its presence.

Naive rats were given three sessions of exposure to 5-sec trials of sound. During these three sessions, the feeder was empty, and the levers were disconnected from the programming apparatus. Following the preexposure sessions, the animals received the same preliminary magazine and lever training as used in Experiment 1, followed by training on the adjacent discrimination.

METHOD

Subjects

Three naive male albino rats, Sprague-Dawley strain, 90 days old at the start of the experiment, served. Before the start of the experiment, the body weights of the animals were reduced to about 80% of that under ad libitum feeding conditions.

Apparatus

The apparatus was the same as that used in Experiments 1 and 2.

PROCEDURE

The levers were disconnected so that responses had no consequence, and the 45-sec

variable-interval timer was arranged to present 5-sec trials of sound through one or other of the speakers in the same irregular order as used in Experiments 1 and 2. The feeder was empty and inoperative. Each animal was given three 30-min sessions in the experimental chamber under these conditions. Following these three sessions, the speakers were unplugged, and the animals received the same magazine and lever training used in Experiment 1. Lever training continued on the 45-sec variable-interval schedule until responding on the two levers was about equal. The speakers were then plugged in, and the animals were trained on the adjacent discrimination as in Experiment 1 for 10 sessions.

RESULTS

The results are summarized in terms of the percentage of adjacent responses in Figure 5. The rate of acquisition was slow, none of the animals reaching an asymptotic level within the 10 training sessions. The results are similar to those from the adjacent discrimination animals (Figure 4) from Experiment 2. Thus, the results obtained in Experiment 2 did not depend on the fact that the sound was an S— during the three exposure sessions and that a response was required to initiate the intertrial interval.

DISCUSSION

The difference between the rapid acquisition of the adjacent discrimination in Experiment 1 (Figure 1) and the slow acquisition obtained in Experiment 3 (Figure 5) is due to the preexposure to the sound the animals received in Experiment 3. In Experiment 1, the sound was novel, whereas in Experiment 3 it was not. This comparison, in conjunction with the slow acquisition of the adjacent discrimination obtained in Experiment 2 and the results of Downey and Harrison (1972) already referred to, strongly suggests that sound novelty is a highly significant variable in determining the rate of acquisition of the adjacent discrimination.

The difference in rates of acquisition of the adjacent discrimination in Experiments 1 and 3 is germane to an idea suggested by Ray and Sidman (1970). They suggested that reinforcers strengthen (or modify) already existing stimulus-response controlling relations rather than creating them, and they further suggest

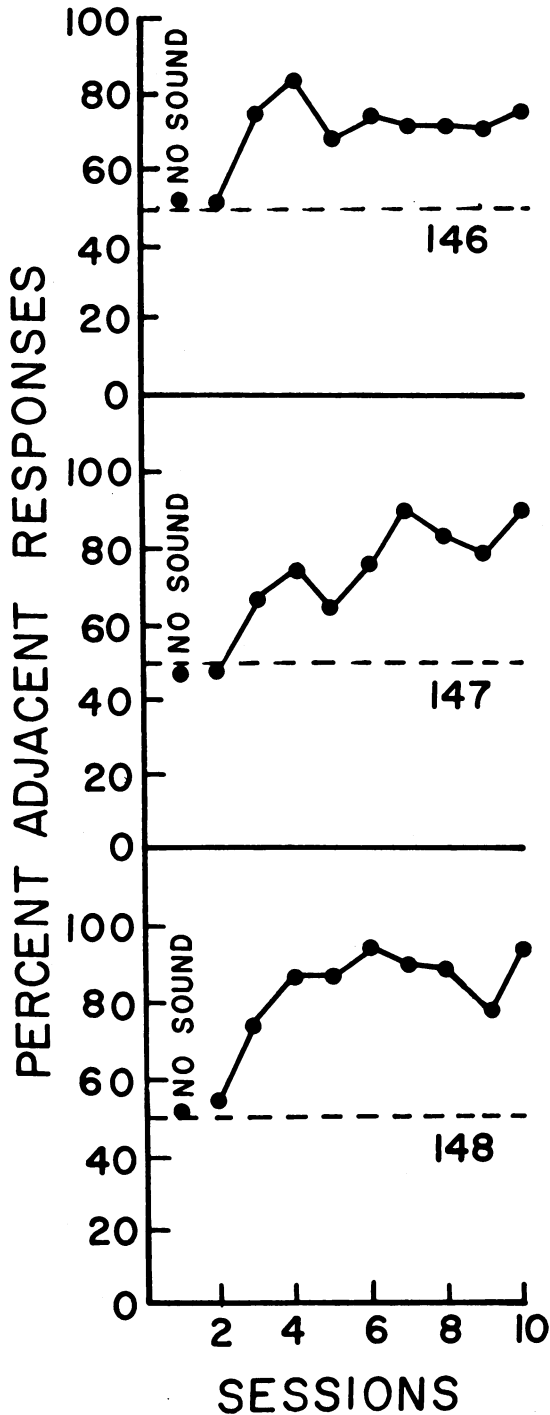


Fig. 5. Percentage of adjacent responses per session. The animals received three sessions of exposure to the sound prior to adjacent discrimination training. The point marked "no sound" gives the percentage of reinforced responses during the last session before the start of discrimination training.

that the strengthening of these existing relations is the basic process underlying the development of discriminations. In Experiment 1, the sound was novel at the start of discrimination training. Results to be presented in Experiment 4 (Table 5) show that rats approach and sniff the sound source for the first few presentations of the first session. Thus, a controlling relation between the sound and responding existed at the beginning of training in Experiment 1, and this controlling relation was reinforced. In Experiment 3, the three sessions of sound exposure weakened or eliminated any responses produced by the sound, so that during adjacent discrimination training there were no (or greatly weakened) controlling relations at the start of training.

EXPERIMENT 4

For both groups in Experiment 1 the sound was paired with the operation of the food magazine for all reinforced responses. While there is little evidence that sounds are effective in autoshaping except in special circumstances (Bilbery & Winokur, 1973; Steinhauer, Davol, & Lee, 1977), there is evidence that responses can be produced in rats and other rodents by autoshaping and omission procedures (Atnip, 1977; Locurto, Terrace, & Gibbon, 1976; Peterson, Ackill, Frommer, & Hearst, 1972; Poling & Poling, 1978; Stiers & Silberberg, 1974). It is possible, then, that the pairing of the sound with the operation of the food magazine resulted in the animals' approaching the sounding speaker and thus pressing the adjacent lever. This explanation would not account for any initial tendency to approach the sound (during the first few trials of the first session), but it may account for the later development of adjacent responding in the second and later sessions for the reversed discrimination animals. Experiment 4 was carried out to determine whether pairing of the sound with magazine operation in magazine-trained rats resulted in the animals' approaching the sounding speaker.

In Experiments 1 and 2, the duration of the sound at each trial was determined by the response latency. Measurement of latencies in representative sessions showed that the maximum duration of a trial was about 5 sec. This value was used for the length of the trials in Experiment 4.

METHOD

Subjects

Eight naive male albino rats (Sprague-Dawley strain) 90 days old at the start of the experiment, were the subjects. Body weight was reduced to about 80% of that under *ad libitum* feeding, and the animals were fed once a day, following their experimental session.

Apparatus

Apparatus was identical with that used in the first two experiments, except that the levers were disconnected but not removed from the experimental chamber.

PROCEDURE

The intertrial interval (45 sec) and the order of presentation (via S1 and S2) of the 5-sec sound trials were identical with those used in the first two experiments. The sessions were also 30 min long. All sessions were recorded on videotape for later analysis of the animals' behavior.

The animals were trained by hand to accept food from the feeder. They were then given one or two sessions in which the magazine operated on the variable-time schedule. Following this preliminary training, the animals were exposed to the sound trials under four conditions.

In the first condition (four animals), there was explicit nonpairing of the sound with magazine operation. This condition was run to determine the effects of the sound in the absence of reinforcement (UCS). The feeder was operated by a 45-sec variable-time schedule, with the restriction that the feeder did not operate within 10 sec of a trial. Two animals were run for 10 sessions and two for three sessions.

In condition 2 (two animals), the magazine was operated at the end of each trial. The purpose of this condition was to approximate the pairing which actually occurred in the first experiment (adjacent discrimination). The animals were studied for 10 sessions.

In condition 3 (two animals), animals were run with explicit nonpairing of the sound with operation of the food magazine for three sessions; in the subsequent 10 sessions, the magazine operated at the end of each trial.

This approximated the pairing that occurred in Experiment 2.

In condition 4 (two animals), the first 10 presentations of the sound in the first session were not followed by operation of the feeder. Thereafter, the magazine operated during 40% of the trials. The purpose of this condition was to approximate the pairing which occurred for the reversed discrimination animals in the first experiment. In this condition in the first experiment, the animals made more than 50% adjacent responses (i.e., less than 50% of responses were reinforced). The pairing of sound and magazine operation was set at 40% to approximate the percentage of reinforced responses. In the nonadjacent condition, the animals tended to make adjacent (nonreinforced) responses for the first few trials of the first session. For that reason, the sound was not paired with the operation of the magazine for the first 10 trials of the first session.

RESULTS

The results of the experiment were obtained by analyzing the videotapes. Initially, representative tapes were viewed a number of times in order to obtain a general idea of what the animals did. It was finally decided to report the frequency of a characteristic response evoked by the sound. The animal approached the sounding speaker, rose on its hind legs, and either sniffed or closely faced the outlet of the sounding speaker. The presence or absence of the response in each trial was noted, and the data are presented as the number of these responses per session. The 30-min session had between 40 and 43 trials.

At least a month after the original reading, the reliability of the videotape analysis was checked by a rereading of five tapes selected at random. There was perfect agreement with the original analysis. Two tapes were independently analyzed by a second person, also with complete agreement with the original analysis.

Novelty of sound. The animals gave between two and eight speaker responses during the first session with no indication that the number of responses depended on the conditions (see first session in Figures 6 and 7). The number of responses in the first session appeared to depend primarily on the novelty of the sound. All animals gave a larger percentage of speaker responses during the first 10 trials of the first session than in the re-

Table 5

Total number of speaker responses, frequency of responses in the first 10 trials of the first session, and frequency of responses in the remainder of the trials of the first session by all animals in Experiment 3. The numbers in parentheses are the number of responses (first number) and the number of trials (second number).

Animal	Total	First 10	Remainder
116	6	30% (3/10)	10% (3/31)
117	3	20% (2/10)	3% (1/30)
119	8	50% (5/10)	9% (3/31)
120	3	20% (2/10)	3% (1/31)
121	4	20% (2/10)	7% (2/30)
122	7	40% (4/10)	10% (3/30)
127	2	20% (2/10)	0% (0/31)
128	3	20% (2/10)	3% (1/31)

mainder of that session (Table 5). West and Harrison (1973) found a similar decrement in responding in cats exposed to intermittent noise. As a general rule, speaker responses did not produce lever presses, in agreement with the results of Experiment 2 (Table 3). Six of the animals gave no lever responses in

the first session, and the other two gave two and three responses, respectively.

Condition 1 (explicit nonpairing). Four animals were run with explicit nonpairing of the sound and feeder operation, two for three sessions, and two for 10 sessions (Figure 6). The results were the same for all animas; speaker responses declined to a low level by the second to third sessions.

Condition 2 (100% pairing). In this condition, 100% pairing of the sound with magazine operation, responding declined to a low level but at a slower rate than was found in condition 1 (Figure 7, top part).

Condition 3. The results of condition 3 are shown in the left side of Figure 6. The pairing of sound with feeder operation on and after the fourth session did not materially change the number of speaker responses. Animal 121 was no different from the unpaired animals. The lever responding of animal 119 was higher than that of the other animals, but response levels during pairing were lower than in the first unpaired session of this animal.

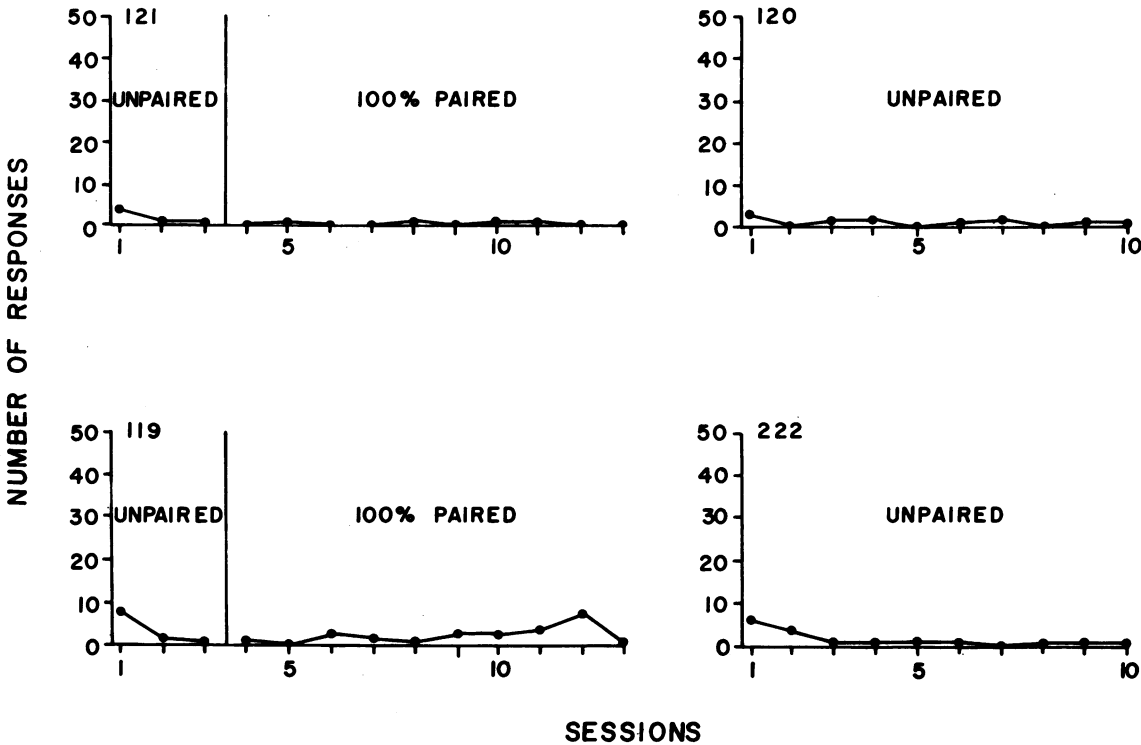


Fig. 6. Number of responses made to the sounding speaker per session. For the animals shown in the left panel, the sound was unpaired with the feeder for three sessions. Feeder operation then followed every presentation (100% pairing) of the sound for 10 sessions. For the two animals shown in the right panel, the sound and feeder operation were unpaired for 10 sessions.

Condition 4. The animals of this condition, 40% pairing of sound with feeder operation, did not differ from those which received 100% pairing. The results are shown in Figure 7 (bottom part).

GENERAL DISCUSSION

The data of Experiment 4 indicate that the results obtained in the nonadjacent discriminations in Experiments 1 and 2 were probably not due to the pairing of the sound with operation of the feeder. None of the conditions produced behavior similar to that reported in automaintenance experiments using rodents (Atnip, 1977; Bilbury & Winokur, 1973; Locurto et al., 1976; Poling & Poling, 1978; Stiers & Silberberg, 1974). In all these experiments, the animals typically showed an acquisition curve in which the percentage of stimulus (usually a retractable lever) presentations to which the animal responded increased to near 100% over one to about eight sessions. In the present experiment, there were neither acquisition curves nor a large number of speaker responses per session.

The general behavior of the animals (119, 120, 121, and 222) exposed to explicit non-pairing was different from that of the animals in the other three groups. The onset of a trial did not appear to have any effect on the stream of behavior, except early in the first session. In contrast, the stream of behavior was clearly modified by trial onsets after two or three sessions of pairing in the other animals (116, 117, 127, and 128). The most common effect of the sound was to produce approach to and activity at the feeder. However, various idiosyncratic responses were also observed. Sometimes the animal would sniff the cage wall under the lever adjacent to the sounding speaker. These responses were highly labile, drifting in and out from animal to animal and from session to session in the same animal.

The failure of the various pairing procedures to produce responding at the sounding speaker cannot be attributed to inadequacies of the sound. The sound was salient and highly locatable, as indicated by the results of the adjacent discrimination in Experiment 1. Also, in the first 10 trials of the first session in all

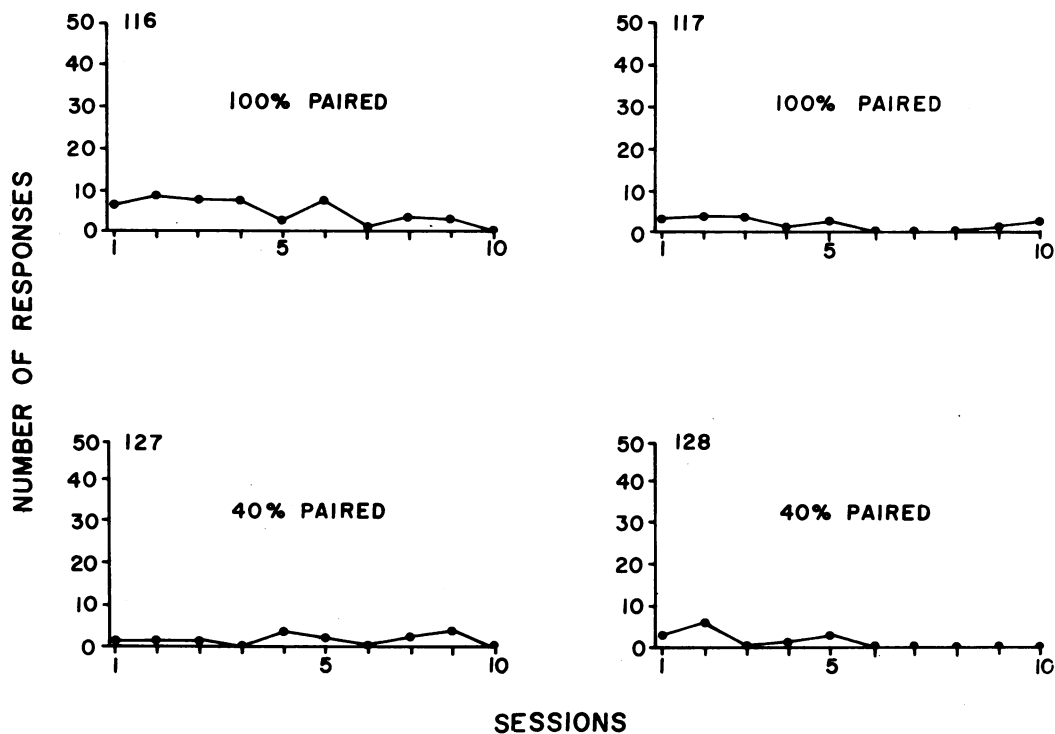


Fig. 7. Number of responses made to the sounding speaker per session. The sound was paired with every feeder operation for the two animals shown at the top of the figure. The feeder operated on 40% of the trials for the two animals shown in the lower part of the figure.

conditions in Experiment 4, speaker responses, when they occurred, were always at the sounding speaker (100% "correct" responses; there were no "errors"). Identical and similar sounds have also been very effective in other discrimination experiments in this laboratory (Downey & Harrison, 1972, 1975; Harrison et al., 1977).

Experiments 2 and 4 strongly indicate that the increase in adjacent responses in the non-adjacent discriminations resulted directly from the reinforcement of the nonadjacent approach and lever press and not from either the novelty of the sound or the pairing of the sound with the operation of the food magazine.

While Experiment 4 showed that the automaintenance procedure did not produce responses at the sounding speaker, it is possible that the lever training the animals received in Experiments 1 and 2 might, if incorporated into Experiment 4, have resulted in the development of speaker responses. For the following reasons, however, it was not possible to lever train the animals before the introduction of the automaintenance procedure. At the end of preliminary training in Experiments 1 and 2, the animals were making between 250 and 400 responses per hour on each lever. If, at this stage, 5-sec sound trials with feeder operation had been introduced, responding on either lever would inevitably have been accidentally reinforced, vitiating the experiment by making it a sloppy version of Experiment 1.

Taken together, the four experiments indicate that rats are equipped with behavioral specializations which enable them to deal efficiently with their everyday environments. If a novel sound occurs it will elicit approach and sniffing responses. If the sound is biologically significant (is associated with a food item, for example) the responses will be reinforced and will occur thereafter in the presence of the sound. If, on the other hand, the sound is of no significance, elicited responses will rapidly decline in strength and the sound will not be responded to on subsequent occasions. Thus, only one or two responses are required for the development of behavior appropriate to the biological neutrality or appetitive significance of a novel acoustic event.

REFERENCES

- Atnip, G. W. Stimulus and response-reinforcer contingencies in autoshaping, operant, classical, and omission training procedures in rats. *Journal of the Experimental Analysis of Behavior*, 1977, 28, 59-70.
- Barry, J. J., & Harrison, J. M. Relation between stimulus intensity and strength of escape responding. *Psychological Reports*, 1957, 3, 3-8.
- Beecher, M. D., & Harrison, J. M. Rapid acquisition of an auditory localization discrimination by rats. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 193-199.
- Bilbery, J., & Winokur, S. Controls for and constraints on autoshaping. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 323-332.
- Brown, C. H., Beecher, M., Moody, D. B., & Stebbins, W. Auditory localization in primates as a function of stimulus bandwidth. *Journal of the Acoustical Society of America*, 1975, 58, S 124.
- Cowan, P. E., & Barnett, S. A. The new-object and new-place reactions of *Rattus rattus* (L). *Zoological Journal of the Linnean Society*, 1975, 56, 219-234.
- Downey, P., & Harrison, J. M. Control of responding by the location of auditory stimuli: Role of differential and non-differential reinforcement. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 453-463.
- Downey, P., & Harrison, J. M. Control of responding by sound location in monkeys: Rapid acquisition in darkness. *Journal of the Experimental Analysis of Behavior*, 1975, 23, 265-269.
- Halgren, C. R. Latent inhibition in rats: Associative or non-associative? *Journal of Comparative and Physiological Psychology*, 1974, 86, 74-78.
- Harrison, J. M., & Abelson, R. The maintenance of behavior by the termination and onset of intense noise. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 23-42.
- Harrison, J. M., & Beecher, M. D. Control of responding by the location of an auditory stimulus: Role of rise time of the stimulus. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 217-227.
- Harrison, J. M., & Briggs, R. M. Orientation and lever responding in auditory discriminations in squirrel monkeys. *Journal of the Experimental Analysis of Behavior*, 1977, 28, 233-242.
- Harrison, J. M., Downey, P., Segal, M., & Howe, M. Control of responding by the location of auditory stimuli: Rapid acquisition in monkeys and rats. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 379-386.
- Harrison, J. M., Iversen, S., & Pratt, R. Control of responding by the location of auditory stimuli: Adjacency of sound and responses. *Journal of the Experimental Analysis of Behavior*, 1977, 28, 243-251.
- Harrison, J. M., & Turnock, M. T. Animal psychophysics: Improvements in the tracking method. *Journal of the Experimental Analysis of Behavior*, 1975, 23, 141-148.
- Locurto, G., Terrace, H. S., & Gibbon, J. Autoshaping, random control, and omission training in the rat. *Journal of the Experimental Analysis of Behavior*, 1976, 26, 451-462.
- Lubow, R. E. Latent inhibition. *Psychological Bulletin*, 1973, 79, 398-407.
- Lubow, R. E., & Moore, A. U. Latent inhibition: Effect of frequency of non-reinforced preexposure to the

- conditioned stimulus. *Journal of Comparative and Physiological Psychology*, 1959, **52**, 415-419.
- Masterton, B., Thompson, G. C., Bechtold, J. K., & Robards, M. J. Neuro-anatomical basis of binaural phase difference analysis for sound localization: A comparative study. *Journal of Comparative and Physiological Psychology*, 1975, **89**, 379-386.
- Mellgren, R. L., & Ost, J. W. P. Discriminative stimulus preexposure and learning of an operant discrimination in rats. *Journal of Comparative Physiological Psychology*, 1971, **77**, 179-187.
- Peterson, G. B., Ackill, J., Frommer, G. P., & Hearst, E. Conditioned approach and contact behavior towards signals for food or brain-stimulation reinforcement. *Science*, 1972, **177**, 1009-1011.
- Poling, A., & Poling, T. Automaintenance in guinea pigs: Effect of feeding regimen and omission training. *Journal of the Experimental Analysis of Behavior*, 1978, **30**, 37-46.
- Ravizza, R. J., Heffner, H. E., & Masterton, B. Hearing in primitive mammals. II. Hedgehog. *Journal of Auditory Research*, 1969, **9**, 8-11.
- Ray, B., & Sidman, M. Reinforcement schedules and stimulus control. In W. H. Schoenfeld (Ed.), *The theory of reinforcement schedules*. New York: Appleton-Century-Crofts, 1970.
- Rescorla, R. A. Pavlovian conditioning and its central processes. *Psychological Review*, 1967, **74**, 71-80.
- Segal, M., & Harrison, J. M. The control of responding by auditory stimuli: Interactions between different dimensions of the stimuli. *Journal of the Experimental Analysis of Behavior*, 1978, **30**, 97-106.
- Steinhauer, G., Davol, G. H., & Lee, A. A procedure for autoshaping the pigeon's key peck to an auditory stimulus. *Journal of the Experimental Analysis of Behavior*, 1977, **28**, 97-98.
- Stiers, M., & Silberberg, A. Lever contact response in rats: Automaintenance with and without a negative response-reinforcement dependency. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 497-506.
- West, C. D., & Harrison, J. M. Transneuronal cell atrophy in the congenitally deaf white cat. *Journal of Comparative Neurology*, 1973, **151**, 377-398.

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